Modulation Characteristics of a Three-Section Master Oscillator Power Amplifier at 1.5 µm

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ABSTRACT:

Direct optical modulation of a 1.55 µm three-section Master Oscillator Power Amplifier has been demonstrated. The temporal response, the optical spectra and the optical modulation amplitude have been analyzed as a function of the frequency and the modulating amplitude. For low modulation amplitude, no spectral broadening was observed up to 1.5 GHz. However, at 12.5 MHz an optical broadening of ~ 4 pm was observed for high modulation amplitudes. At this frequency an extinction ratio of 42 dB has been achieved. The modulation amplitude degrades for frequency values higher than 30 MHz. The device performance under modulation at 12.5 MHz is interesting for its application as laser source for CO_2 detection by differential absorption LIDAR operating in the Continuous Wave Random Modulation mode.

Key words: High brightness semiconductor lasers, direct modulation, master oscillator power amplifier.

1.- Introduction

Nowadays an increasing number of applications such as free space optical communications, differential absorption LIDAR (DIAL), metrology and frequency doubling require high brightness laser sources with stable and narrow spectral width. Modern high-brightness semiconductor lasers have the potential to fulfill these requirements at a low cost and incorporate in addition the acknowledged advantages of laser diodes in terms of low weight and size and high conversion efficiency. The monolithically integrated Master Oscillator Power Amplifier (MOPA) architecture has been regarded as one promising candidate to satisfy all these requirements [1, 2].

An integrated MOPA usually consists of two sections: an index guided single lateral mode waveguide section acting as a master oscillator (MO), and a power amplifier (PA). The master oscillator is either a Distributed Bragg Reflector (DBR) or a Distributed Feedback (DFB) laser, while the power amplifier is a flared section with antireflection coated output facet. In a MOPA working in ideal conditions, the single mode generated by the MO is amplified by the PA keeping its initial beam quality. One additional potential advantage of the MOPA configuration is the fact that the high optical power delivered by the device could be directly modulated either by a relatively small excursion of the driving current of the MO or by the modulation of the current injected in an additional modulation section inserted between the MO and the PA sections. This advantage has been invoked to propose a three-section integrated MOPA as the transmitter unit of a DIAL system operating in the Continuous Wave Random Modulation (CW-RM) mode [1].

Although all these advantages have been compromised by the emission instabilities appearing even when simple MOPA devices are driven in CW conditions [3-6], recent curved and tilted designs have overcome the problem and we have recently demonstrated three section devices showing high emission stability in a broad region of CW driving conditions [2].

In this work we present the first experimental results on the direct modulation of an integrated three-section MOPA with stable emission in the 1.5 μm spectral region. The device and the experimental set-up are briefly described in section 2. In section 3 the experimental results are presented and discussed. The conclusions are drawn in section 4.

2.- Experimental Setup

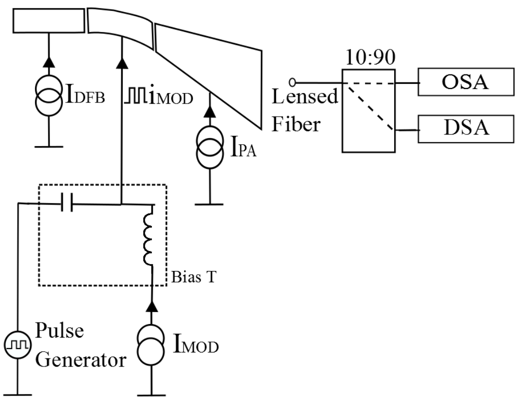

Fig. 1: Schematic of the device geometry and the experimental setup for the acquisition of the optical spectra and the time traces. OSA: optical spectrum analyzer. DSA: digital signal analyzer.

The device is a three section MOPA with emission wavelength close to 1.55 μm. It consists of a 1mm long DFB, a 1 mm long modulation section and a 3 mm long PA (4º). Its most remarkable feature is the bended geometry of the modulation section inserted between de straight MO section and the flared PA section (which output facet is slightly tilted accordingly) (Fig. 1). All the details of the epitaxy, the geometry and the fabrication process can be found in [2]. The pitch of the DFB grating of this device was different from the pitch of the device reported in [2] and this resulted in a slightly different emission wavelength, a lower maximum output power (180 mW) and a slightly different attenuation effect of the modulation current. The experimental setup was designed for driving each section separately as shown in Fig. 1. A CW current, I_{DFB}, is supplied to the DFB section. The modulating current, i_{MOD}, is the superposition of two signals in a Bias-T: a CW bias current I_{MOD} and, the output signal from a Pulse Pattern Generator (Anritsu MU181020A). The Pulse Pattern Generator (PPG) supplies a square wave with a peak-to-peak output voltage Vpp up to 2.5V at a given frequency f_{clock}. When higher Optical Modulation Amplitude (OMA) was required, an RF amplifier (20 dB gain) (Mini-Circuits ZFL-2500VH+) not shown in Fig.1 was used. Finally, a CW current source supplies I_{PA} to the PA section.

A fraction of the output power was collected using a lensed fiber (Yenista FP002301). The optical signal was split in two branches: one was directed to the Optical Spectrum Analyzer ANDO AQ6315 (resolution 0.05 nm) and the other to a 20 GHz optical module of a Digital Signal Analyzer (Tektronix DSA8000). For measuring the total output power, a thermal broad area detector was used (GENTEC UP19K-30H-H5). All the measurements were performed at a constant temperature of 15°C.

3.- Experimental Results

Fig 2 shows the output power as a function of I_{MOD} at I_{DFB} = 300 mA and I_{PA} = 2.5 A. As shown in Fig 2, for I_{MOD} around zero the output power is ~ 50 mW. In order to reduce the output power down to zero, a negative current I_{MOD} must be supplied to the modulation section.

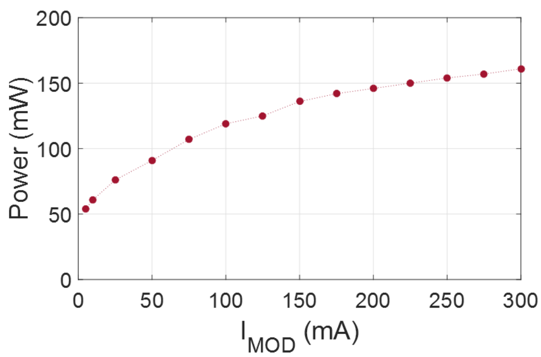

Fig. 2: P-I_{MOD} characteristics. I_{DFB} = 300 mA and I_{PA} = 2.5 A

In the following we present the temporal response and the corresponding output spectra by changing the modulation conditions at fixed values of the bias: I_{DFB} = 300 mA, I_{MOD} = 100 mA and I_{PA} = 2.5 A.

Fig. 3 shows the measured optical response at different f_{clock} for a peak to peak square voltage equal to 2.5 V_{pp}. Fig 4 shows Optical Modulation Amplitude (OMA) for f_{clock} ranging between 1 MHz and 1.5 GHz.

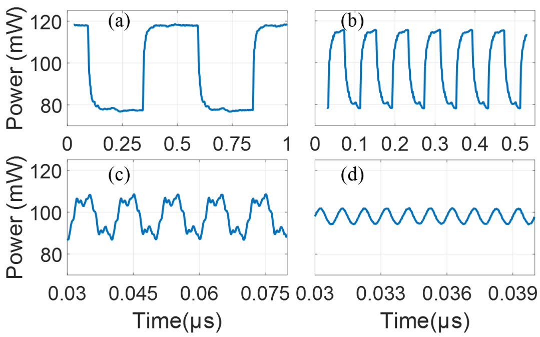

Fig. 3 Temporal optical response at different f_{clock}: (a) 2 MHz, (b) 12.5 MHz, (c) 100 MHz, (d) 1 GHz; The PPG output was set to the maximum value, 2.5 Vpp. I_{DFB} = 300 mA, I_{MOD} = 100 mA and I_{PA} = 2.5 A.

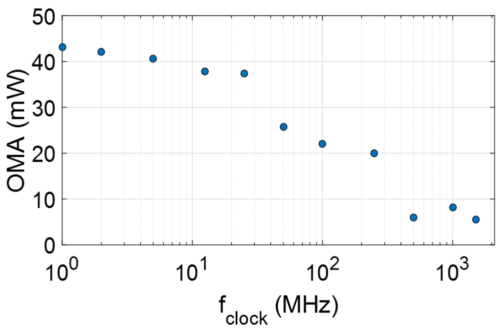

Fig. 4: Optical Modulation Amplitude (OMA) vs. clock frequency for the driving conditions in Fig. 3.

At the lowest frequencies (see Fig. 3a) the output power presents the square shape of the modulation current but when increasing the frequency a progressive degradation of the waveform is appreciated (see Fig. 3b-c) together with a drastic reduction of the OMA (see Figs. 3b-c-d and 4). At the highest frequencies a low amplitude almost sinusoidal response is obtained (see Fig. 3d). At a frequency of 12.5 MHz, which is the modulation frequency of the CO_2 atmospheric LIDAR application, the response is almost square with symmetrical rise and fall times (10-90%) of around 12 ns. Above 30 MHz the square signal is distorted with a clear drop of the amplitude. The poor high frequency response is attributed to a combination of poor impedance matching and electrical parasitics.

Fig 5 shows the optical spectra at the modulation conditions of Fig. 3. Within our spectral resolution there is no evidence of spectral broadening. The shifts in the peak wavelength are attributed to small changes in the chip temperature.

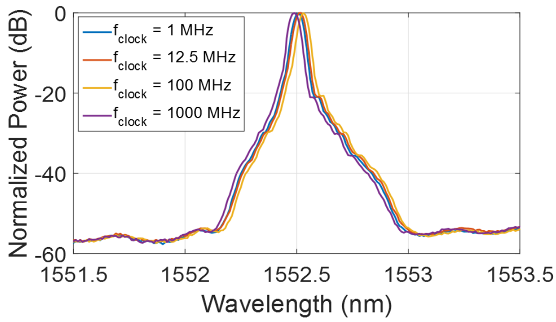

Fig. 5: Optical spectrum for the driving conditions of Fig. 3

Fig. 6 shows the temporal response for different modulation amplitudes V_{pp} at a fixed frequency of 12.5 MHz and the same bias conditions as in previous figures (I_{DFB} = 300 mA, I_{MOD} = 100 mA and I_{PA} = 2.5 A).

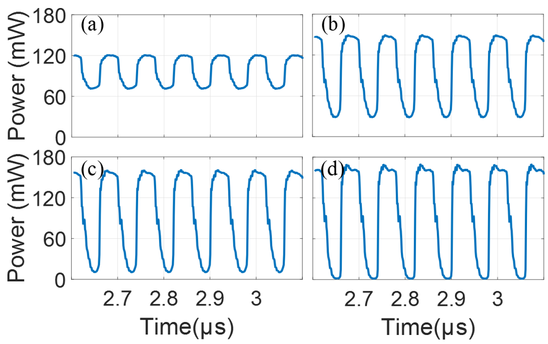

Fig. 6: Temporal optical response for different Vpp: (a) Vpp = 3.75 V, (b) Vpp = 7.5 V, (c) Vpp = 11.25 V, (d) Vpp = 18.75 V. I_{DFB} = 300 mA, I_{MOD} = 100 mA and I_{PA} = 2.5 A.

By increasing the modulation amplitude at a constant modulator bias current, there is a large increase of the OMA together with an improvement of the Extinction Ratio (ER), as the minimum emitted power takes a very low value. In these conditions, the optical power emitted by the DFB is absorbed by the modulator, which is driven at a very low voltage bias producing thus a negative photocurrent.

Fig 7 shows the OMA and the ER as a function of the modulation amplitude. For modulation amplitude higher than ~ 18 V_{pp} the OMA saturates at ~ 170 mW with an ER of ~ 42 dB.

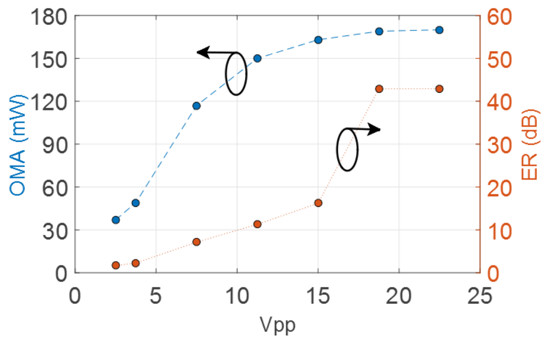

Fig. 7: OMA and ER as a function of the modulation amplitude V_{pp}. f_{clock} = 12.5 MHz, I_{DFB} = 300 mA, I_{MOD} = 100 mA and I_{PA} = 2.5 A.

The optical spectra corresponding to the temporal traces in Fig. 6 are shown in Fig. 8. The emission peak at the maximum V_{pp} is ~ 95 pm red shifted in comparison with the minimum V_{pp}. This effect is attributed to a higher heat dissipation and average temperature when increasing the modulation amplitude. A broadening of the measured optical spectrum for the maximum V_{pp} was observed (Full Width Half Maximum FWHM ~ 0.049 nm) in comparison with the values measured in CW conditions (FWHM ~ 0.045 nm).

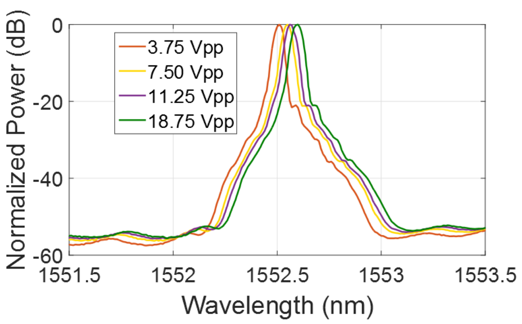

Fig. 8: Optical spectra for different values of V_{pp}. I_{DFB} = 300 mA, I_{MOD} = 100 mA and I_{PA} = 2.5 A.

4.- Conclusion

Direct modulation of a three-section MOPA emitting at 1.55 µm has been demonstrated for CO_2 atmospheric LIDAR application. The maximum ER achieved for the desired frequency operation (f_{clock} = 12.5 MHz) was 42 dB. The frequency response is strongly limited by the driving circuit and further improvements need to be done in the set-up in order to use this device in applications requiring high frequency operation, such as free space optical communications.

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